Attorney Docket No. 046972-0102
Application No. 10/511,734

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicants:	Davor **PROTIC** *et al.*
Title:	**POSITION-SENSITIVE GERMANIUM DETECTORS HAVING A MICROSTRUCTURE ON BOTH CONTACT SURFACES**
Application No.:	10/511,734
Int'l. Filing Date:	04/03/2003
371(c) Date:	10/18/2004
Examiner:	Shun K. LEE
Art Unit:	2884
Confirmation No.:	2536

APPELLANT'S BRIEF UNDER 37 C.F.R. §41.31

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Alexandria, VA 22313-1450

Sir:

This Brief on Appeal is being filed under the provisions of 37 C.F.R. § 41.37. A payment in the amount of $540.00 covering the 37 C.F.R. 41.20(b)(2) appeal brief fee is enclosed as a credit card authorization. If this fee is deemed to be insufficient, authorization is hereby given to charge any deficiency (or credit any balance) to the undersigned's deposit account 19-0741.

REAL PARTY IN INTEREST

The real party in interest is the assignee, Forschungszentrum Jülich, GmbH.

RELATED APPEALS AND INTERFERENCES

None.

STATUS OF CLAIMS

Claims 1 and 3-12 are pending and are all rejected. Claim 2 is canceled. All of the claims are on appeal and are set forth in the Claims Appendix.

STATUS OF AMENDMENTS

The claims stand as amended by the Applicants' submission under 37 C.F.R. § 1.111 of July 30, 2007. There were no non-entered amendments after final.

SUMMARY OF CLAIMED SUBJECT MATTER

Applicants recommend that the Board begin by reading the "Background" section of the Argument, which is not a summary of the claimed subject matter, but relevant to its understanding.

In the following description, the abbreviation "RN" stands for "reference numeral".

The present application deals with semiconductor-based detectors for, *e.g.*, charged particles or photons (*see, e.g.*, page 1, lines 5-8). In particular, the detectors are designed to detect the approximate position at which a particle impacts the detector (*see, e.g.*, page 1, line 5). Detectors according to the present application have a surface region with an amorphous layer (*see, e.g.*, page 6, lines 11-12; page 6, line 31 – page 7, line 9; Fig. 1, RN 2; Fig. 2, RN 2) and a structured metallic layer (*see, e.g.*, page 5, lines 21-22; page 6, lines 11-23; Fig. 1, RN 4; Fig. 2, RN 4), where the structure of the metallic layer is continued into the amorphous Germanium layer (*see, e.g.*, page 3, lines 20-22; page 5, lines 29-31; Fig. 1, RNs 2, 4; Fig. 2, RNs 2, 4).

Claim 1 relates to a position-sensitive detector (*see, e.g.*, page 5, lines 18-22; Fig. 1, RN 1; Fig. 2, RN 1) for measuring charged particles comprising a crystalline substrate and a surface region (*see, e.g.*, page 5, lines 18-22; Fig. 1, RN 1; Fig. 2, RN 1), the surface region comprising an amorphous layer (*see, e.g.*, page 6, lines 11-12; page 6, line 31 – page 7, line 9; Fig. 1, RN 2; Fig. 2, RN 2) with a structured, metallic layer disposed above it (*see, e.g.*, page 5, lines 21-22; page 6, lines 11-23; Fig. 1, RN 4; Fig. 2, RN 4), wherein the structure of the metallic layer continues through the amorphous layer (*see, e.g.*, Fig. 1, RN 5; Fig. 2, RN 5)

and at least partially into the crystalline substrate (*see, e.g.*, page 3, lines 20-22; page 5, lines 29-31; Fig. 1, RNs 2, 4; Fig. 2, RNs 2, 4).

Claim 12 relates to a method of producing a position-sensitive detector for measuring charged particles (*see generally*, page 6 lines 31-32), comprising: providing a crystalline substrate; disposing on the substrate an amorphous Germanium layer (*see, e.g.*, page 6, lines 31-33; Fig. 1, RN 2; Fig. 2, RN 2) disposing on the amorphous Germanium layer a metallic layer (*see, e.g.*, page 6, line 33-page 7, line 2; Fig. 1, RN 4; Fig. 2, RN 4); removing portions of the metallic layer, the amorphous Germanium layer and the crystalline substrate such that at least one structured electrode is formed (*see, e.g.*, page 7, lines 2-7; Fig. 1, RNs 2, 4 and 5; Fig. 2, RNs 2, 4 and 5).

The foregoing summary of the claimed subject matter is not intended to be limiting or to refer to all potential supporting material.

GROUND OF REJECTION TO BE REVIEWED ON APPEAL

The following grounds of rejection are to be reviewed on appeal:

1. Claims 1 and 3-10 and 12 are rejected under 35 U.S.C. §103(a) over Hamacher *et al.* (Performance of position -sensitive germanium detectors in nuclear reaction experiments, Nuclear Instruments & Methods in Physics Research, Vol. A295, no. 1-2 (October 1990), pp. 128-132) in view of Luke *et al.* (Amorphous Ge bipolar blocking contacts on Ge detectors, IEEE Transactions on Nuclear Science, Vol. 39, no. 4 (August 1992), pp. 590-594).

2. Claim 11 is also rejected under 35 U.S.C. §103(a) over Hamacher in view of Luke, and argued separately.

3. Claim 8 is rejected under 35 U.S.C. § 112 ¶1 for lack of written description support.

ARGUMENT

A. Background

The present application deals with semiconductor-based detectors for, *e.g.*, charged particles or photons (*see, e.g.*, page 1, lines 5-8). In particular, the detectors are designed to

detect the approximate position at which a particle impacts the detector (*see, e.g.*, page 1, line 5).

Such detectors can be produced from, *e.g.*, crystalline Germanium having a structure on both sides (*see, e.g.*, page 1, lines 15-20). The Germanium has multiple electrical contacts on either side. When a particle strikes the detector, it creates an electron-hole pair (*see, e.g.*, page 1, lines 22-24). The electron and hole each migrate to a nearby oppositely charged contact, causing a current to be measured (*see, e.g.*, page 1, lines 24-25).

Contacts might be structured as follows. On one side of the detector, for example, a series of strips could be formed, separated by grooves (*see, e.g.*, page 3, lines 10-17). On the other side of the detector, another series of strips could be formed, but running perpendicular to the strips on the other side (*see, e.g.*, page 3, lines 10-17).

In the past, such detectors were manufactured using Boron implantation for one side of the detector, and Phosphorous implantation for the other side (*see, e.g.*, page 1, lines 18-20). Phosphorous implantation, however, produced radiation damage in the crystal, decreasing its effectiveness (*see, e.g.*, page 2, lines 1-6). The radiation damage could be reduced by heating to a tempering temperature, but this in turn caused the diffusion of contaminants into the detector (*see, e.g.*, page 2, lines 8-20).

One attempt to avoid the problems associated with Phosphorous implantation was the use of an amorphous Germanium layer (*see, e.g.*, page 4, lines 27-32). The layer was applied to a substrate, and a metal layer was applied with a strip structure (*see, e.g.*, page 4, lines 27-32). However, experimentation showed that such detectors exhibited a comparatively poor energy resolution and a relatively large number of measurement errors in the energy measurement (*see, e.g.*, page 5, lines 1-5).

B. The Prior Art Context

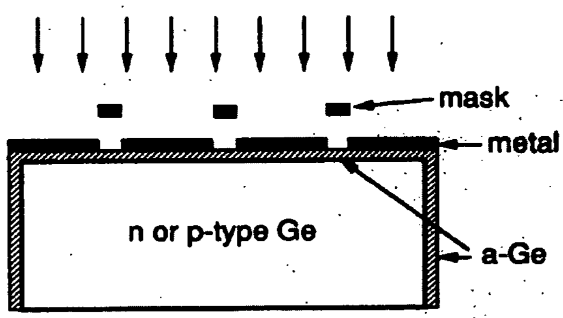
Pending claims 1 and 3-12 currently stand rejected under 35 U.S.C. § 103(a) over Hammacher, *et al.*, "Performance of position-sensitive Germanium Detectors in Nuclear Reaction Experiements Nuclear Instruments & Methods in Physics Research, Vol. A295, no. 1-2 (October 1990), ("Hammacher") in view of Luke, *et al.*, Amorphous Ge Bipolar Blocking

Contacts on Ge Detectors, IEEE Transactions on Nuclear Science, Vol. 39, No. 4 (August 1992), pp. 590-594 ("Luke").

The Hammacher reference (1989) is entitled "Performance of position-sensitive germanium detectors in nuclear reaction experiments", and names the first inventor, Mr. Protic, as a co-author.

The Hammacher reference discusses Germanium-based detectors generally. It does not teach or suggest at any point the use in the detector of an amorphous layer. Rather, Hammacher is cited for the disclosure of Fig. 1, which shows a method of producing a Germanium detector. This method uses a contact having structured Aluminum on top of Boron. The figure shows the step of "transferring the structure into the semiconductor material by etching". The Boron contact used by Hammacher was known to have excellent properties, and indeed is still used today. *See* Protic Declaration, ¶¶5-6 and 9-10.

The Luke reference (1992) is entitled "Amorphous Ge Bipolar Blocking Contacts on Ge Detectors". Luke discusses forming electrical contacts using sputtered amorphous Germanium on Ge crystals. Luke teaches that the amorphous Germanium layer is unstructured, as shown in Fig. 8 of Luke, which is reproduced here:



In fact, the authors of Luke suggest that the amorphous Germanium layer should be left intact to form as a passivation layer:

> ...the a-Ge coating which was also deposited on the side of the device during formation of the a-Ge was left intact to function as a surface passivation layer.

Luke published a later paper ("Amman", 2007) in which he and others evaluated the use of amorphous Germanium (Evidence Appendix, Attachment 2), and in which he again suggested that amorphous Germanium be left intact to function as a passivation layer:

> Furthermore, the inter-contact surfaces for both contact types should be passivated to obtain long-term detector stability, thereby necessitating additional processing steps. An alternative technology capable of producing position-sensitive detectors is the amorphous-semiconductor contact developed at LBNL. With this technology, the contacts are formed by first coating all surfaces of the Ge crystal with a thin film of high-resistivity amorphous Semiconductor (typically Ge or Si). Metal layers in the desired pattern are then deposited on top fo the amorphous layer to complete the contact fabrication....The advantages of this technology are...(3) complete surface passivation, since amorphous Ge (a-Ge) layers are commonly used for Ge passivation.

Amman, p. 887. Thus, Luke teaches the use of an amorphous Germanium layer, but teaches that it should be left unstructured to form a passivation layer.

Not only was there a teaching in the art to use unstructured amorphous Germanium as a passivation layer, there was also an belief that amorphous Germanium functioned relatively poorly with respect to energy resolution. As is noted in the specification of the instant application at page 5, lines 1-5:

> However, experiments have shown that in the case of the above-named detector with the structured metallic surface, only a comparatively poor energy resolution can be achieved. Furthermore, a relatively large number of measuring errors occur in the energy measurement.

The declaration of Davor Protic confirms the belief in the art at the relevant point in time, *see* ¶¶ 11-12.

This belief is further confirmed by the Amman publication at page 889, which states:

> Despite the substantial success achieved with Ge-based detectors fabricated using amorphous-semiconductor contacts, issues remain to be resolved before the full potential of the devices will be realized in large-scale instruments. These issues include excessive leakage at temperatures significantly above that of liquid nitrogen, leakage current degradation with

> temperature cycling, and charge collection to inter-contact surfaces. The excessive leakage current issue was discussed in the previous section and, can be addressed through the development and optimization ofthe a-Ge/Ge/a-Si detector configuration and other similar structures. Cycling temperature of an amorphous-contact Ge detector from cryogenic temperature to room temperature and then back to a low temperature again typically causes the leakage current of the detector to increase at the operating temperature. Such temperature cycling is unavoidable in the detector evaluation and instrument assembly process. The gradual increase in the leakage caused by this cycling can ultimately lead to degraded energy resolution.

In summary, the Hammacher reference teaches the use of a structured Boron-based contact, but does not suggest the use of amorphous Germanium. The characteristics of the Boron contact were known to be excellent. The Luke reference teaches the use of an unstructured amorphous Germanium layer, and teaches that the layer should be left intact for passivation purposes. It was believed in the art at the relevant point in time that amorphous Germanium provided a relatively poor contact with respect to energy resolution. There is <u>no prior art</u> of record that teaches (1) that there was motivation to improve the blocking contact of Boron; (2) that there was an expectation that amorphous Germanium would improve the already excellent qualities of Boron, (3) that if used, the amorphous Germanium should layer should be structured or (4) that the structure of the amorphous Germanium and metal layers should continue into the substrate. It was only through the Applicants' teaching of a *structured* amorphous layer that the surprising increase in energy resolution was revealed.

C. The Rejection Over Hammacher In View Of Luke Is Improper

1. The Rejection Of Claims 1, 3-10 and 12 Was Improper

Applicants submit that the application should be allowed for two reasons. First, the Examiner improperly discounted the evidence of non-obviousness contained in the declaration of Davor Protic, submitted January 31, 2008 (Evidence Appendix, Attachment 1). Second, if the declaration of Protic and supporting references are considered in view of the actual teachings of the prior art, it is clear that motivation to combine the Hammacher and Luke references did not exist. In fact, there was an active belief that the use of an amorphous layer as part of a contact would reduce the energy resolution of the detector.

The Declaration Of Protic Was Improperly Discounted

In the Office Action mailed April 15, 2008, the Examiner entered but discounted the declaration of Davor Protic, stating on page 6:

> The declaration under 37 CFR 1.132 filed 31 January 2008 is insufficient to overcome the rejection of claims 1 and 3-12 based on Hammacher et al. in view of Luke et al. as set forth in the last Office action because it refers only to the system described in the above-referenced application and not to the individual claims of the application. Thus, there is no showing that the objective evidence of non-obviousness is commensurate in scope with the claims. *See* MPEP § 716.

The Examiner's reasoning appears to be referring to the requirement of "nexus" between certain evidence of non-obviousness and the claims of an application. In some instances, it is appropriate for the Office to require a nexus between the claims and the evidence, in order to ensure that the evidence is relevant to the question of obviousness. For example, if an applicant presents evidence of the commercial success of a product incorporating an invention, it is appropriate to require evidence that the claimed features produced the success, as opposed to a good marketing campaign.

In the present case, however, the declaration of Protic was not submitted to present this type of evidence. Instead, it was presented to rebut the particular motivation to combine Hammacher with Luke put forward by the Examiner. Specifically, the Examiner had reasoned that a person of skill in the art would combine Hammacher with Luke in order to provide Hammacher with a good blocking contact. The declaration of Protic responds to this specific finding, providing evidence that (1) such motivation did not exist, *see* ¶¶ 5-8, and (2) that there was an belief that the use of amorphous Germanium would degrade the energy resolution of a detector, see ¶¶ 11-12.

Thus, the Protic declaration is directly tied to the Examiner's reasoning. Applicants respectfully submit that, if the Protic declaration is not relevant to the claims under examination, then neither is the Examiner's motivation to combine references.

No Motivation To Improve Blocking Contact

The Examiner combined Hammacher with Luke, reasoning that a person of skill in the art would be motivated to provide Hammacher with a good blocking contact. Applicants respectfully submit that this is a straw-man argument having little relation to reality. As explained by Mr. Protic, the Boron-doped contact of Hammacher already provides an excellent contact. *See* Protic Decl. ¶¶5, 6, 8 and 11-12. There was, therefore, nothing motivating persons of skill in the art to improve upon the blocking contact qualities of what was already known.

As explained by Mr. Protic, the following features are of interest with regard to a detector:

- Of importance is the accuracy in the energy measurement.
- Of importance is to provide a detector with a good energy resolution in the measurement.
- Of importance is to provide a durable detector.
- It is often of importance to provide a detector with a good positional resolution.

See Protic Decl. ¶7.

Typically, blocking contacts are provided to reduce the leakage current, which can affect the energy resolution of the device. *See* Protic Decl. ¶9. At temperatures where Germanium detectors are used commercially, however, the leakage current of a detector is quite small. *See* Protic Decl. ¶10. There was therefore no motivation to provide better blocking contacts for these sorts of detectors at the relevant point in time, because doing so would not have improved the energy resolution. *See* Protic Decl. ¶10.

As further evidence of this, Applicants submitted as Attachment 2 to their January 31, 2008 supplemental response a newer article by Luke, with the citation M. Amman, P.N. Luke, S.E. Boogs, NUCLEAR INSTRUMENTS AND METHODS IN PHYSICS RESEARCH A 579 (2007) 886-890 ("Luke II").

According to this article, page 887, left column, paragraph 1, Luke teaches:

> The standard contact technology for such a detector consists of a Li-diffused n+ contact and a B-implanted p+ contact. Both contact types are robust, can withstand high electrical fields, and lead to a low charge carrier injection.

The phrase "[l]ead to a low charge carrier injection" means that the leakage current is small.

Moreover, Hammacher itself makes no reference to the Boron contact as a blocking contact, nor does it express any desire for a better blocking contact than Boron.

Amorphous Germanium Was Believed To Decrease Energy Resolution

There was further no motivation to combine Hammacher with Luke at the relevant point in time, because a person of ordinary skill in the art would have expected an amorphous Germanium contact to decrease the energy resolution of the device. Thus, there was an active disbelief that the invention would work at the relevant point in time.

As explained by Mr. Protic, experiments carried out by others with a contact of structured metal on top of an unstructured, amorphous Germanium layer resulted in a relatively poor energy resolution. *See* Protic Decl. ¶¶ 11-12; *see also* top of page 5 of present application.

Thus, the person of ordinary skill in the art would have had no incentive to combine Hammacher with Luke. He or she would have expected that the replacement of Boron-doped contacts with amorphous Germanium contacts would have decreased the energy resolution of the device, while not appreciably decreasing the leakage current over the already good Boron-doped contact.

The present application differs from the prior art at least in that it teaches the use of a structured amorphous layer. In reality, a person of skill in the art would have had no basis to believe that there would be any significant difference between a structured or unstructured amorphous layer. Since the person skilled in the art expected a poor energy resolution with the use of an unstructured layer for the above mentioned reasons, it was not obvious for a person skilled in the art that the subject matter of claim 1 would lead to a detector with a significantly improved energy resolution.

Importantly, the Examiner has not cited a single prior art reference that suggests that energy resolution can be increased by providing a structured, amorphous layer. Rather, the balance of the evidence of record suggests that an amorphous Germanium layer, regardless of its structure, will perform poorly. Teachings regarding the difference between a structured and unstructured amorphous layer appear to be missing from the cited art.

It is believed that a structured amorphous layer was first used by the present inventors, and that the surprising benefits of this feature were unknown to a person of skill in the art at the time the invention was made. *See* Protic Decl. ¶ 12.

Therefore, it would not have been obvious to combine Hammacher with Luke to arrive at claims 1, 3-10 or 12.

2. The Rejection Of Claim 11 Was Further Improper

Claim 11 is further patentable over the combination of Hammacher and Luke. Claim 11 specifies that "the mutual spacing is less than 20 μm." Neither Hammcher nor Luke disclose or suggest this feature.

The Examiner points to Hammacher as disclosing spacing less than 100 μm. But this is not disclosure of the more specific 20 μm. The references therefore can not be used to establish a *prima facie* rejection per MPEP § 2143.03, because not all limitations are taught by the combination of references.

D. Rejection of Claim 8 Under 35 U.S.C. § 112 ¶1 Is Improper

Claim 8 was also rejected under 35 U.S.C. § 112 ¶1. The specification clearly teaches the application of an amorphous Germanium layer by sputtering or vapor deposition followed by the application of a metal layer at page 6, line 31 – page 7, l. 9. The method does not recite that the layer is subsequently doped, but rather that the metal electrode is "subsequently" applied, whereas the doping step for the Boron doped layer at the opposite side of the detector is specifically recited. *See* p. 7, lines 7-9. The Applicants must be able to claim at least that which is specifically recited: an undoped amorphous layer deposited prior to metallization.

Summary

Applicants respectfully submit that the claims should be allowed, because there is no case of non-obviousness under 35 U.S.C. § 103(a). When the evidence and prior art are properly taken into account, there is no motivation to combine the Hammacher and Luke references. In fact, there was an active belief that the use of amorphous Germanium would lead to decreased energy resolution.

Respectfully submitted,

Date Dec. 1, 2008 (Monday)

By [signature]

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CLAIMS APPENDIX

1. A position-sensitive detector for measuring charged particles comprising a crystalline substrate and a surface region, the surface region comprising an amorphous layer with a structured, metallic layer disposed above it, wherein the structure of the metallic layer continues through the amorphous layer and at least partially into the crystalline substrate.

2. (Canceled)

3. The position-sensitive detector according to claim 1, wherein the amorphous layer is formed from germanium or silicon.

4. The position-sensitive detector according to claim 1, wherein the metallic layer comprises aluminium, palladium or gold.

5. The position-sensitive detector according to claim 1, wherein the substrate is formed of germanium, silicon or a III-V compound.

6. The position-sensitive detector according to claim 1, wherein the structure of the metallic layer is formed from segments having a mutual spacing of less than 200 μm.

7. The position-sensitive detector according to claim 1, wherein the amorphous layer is disposed on a semiconductor material.

8. The position-sensitive detector according to claim 3, wherein the amorphous layer is not doped.

9. Tomograph or Compton camera with a detector according to claim 1.

10. The position-sensitive detector according to claim 6, wherein the mutual spacing is less than 100 μm.

11. The position-sensitive detector according to claim 6, wherein the mutual spacing is less than 20 μm.

12. A method of producing a position-sensitive detector for measuring charged particles, comprising:

providing a crystalline substrate;

disposing on the substrate an amorphous Germanium layer;

disposing on the amorphous Germanium layer a metallic layer;

removing portions of the metallic layer, the amorphous Germanium layer and the crystalline substrate such that at least one structured electrode is formed.

EVIDENCE APPENDIX

The evidence appendix contains the following attachements, which were submitted on Janaury 31, 2008 as Attachments 1 and 2 to the Applicants' amendment. The Attachments were entered into the record and discussed with the Examiner's action of April 15, 2008.

Attachment 1: Declaration of Inventor Davor Protic, together with Exhibits 1 and 2, submitted 1/31/2008, executed 1/21/2008.

Attachment 2: M. Amman, P.N. Luke, S.E. Boogs, NUCLEAR INSTRUMENTS AND METHODS IN PHYSICS RESEARCH A 579 (2007) 886-890 ("Luke II").

Attachment 1

Declaration of Davor Protic

Atty. Dkt. No. 046972-0102

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant:	Davor PROTIC et al.
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DECLARATION UNDER 37 C.F.R. § 1.132

1. I, Davor Protic, do hereby declare as follows.

2. I am a co-inventor named in the captioned application, and was employed 38 years by the current assignee of the application up to 30.April 2007. Since 1.Mai 2007 I have been a pensioner.

3. I have a Master of Science degree in Solid State Physics given from the University of Zagreb, Croatia.

4. I have more than 30 years of experience developing semiconductor-based position sensitive detectors for charged particles or photons.

5. At the time the present application was originally filed, it was well-known that a detector comprising a Boron doped contact was a durable detector with an excellent energy resolution in the measurement. This is still true today.

6. As evidence of this, I have attached as exhibit 1 a Web-site print out from www.ortec-online.com. Ortec is a well-known producer and seller of corresponding detectors. As shown in the Web site in the bullet points near the top of the first page, ORTEC

is using a Boron ion implanted outer contact. According to the Ortec-document, the contact is "ultra stable". A corresponding detector shows a lot of excellent properties.

7. The following features are of most interest with regard to a detector in the field of the application: (1) of importance is the accuracy in the energy measurement; (2) of importance is to provide a detector with a good energy resolution in the measurement; (3) of importance is to provide a durable detector; and (4) it is often of importance to provide a detector with a good positional resolution.

8. However, a person skilled in the art is never interested in improving detector blocking contacts, since such detectors, in the commercial marketplace, do not need better blocking contacts.

9. Detectors in the commercial marketplace do not need better blocking contacts because, in the typical operating environment, better blocking contacts would not increase the energy resolution. The energy resolution of a detector depends on many factors. One factor is the leakage current of a detector. The leakage current of a detector depends on the operating temperature and the blocking contact.

10. The leakage current of a detector is small if the operating temperature is low. This is especially true for detectors made of Germanium. The typical operating temperature of a detector made of Germanium is 77 K and consequently low. As a result, the leakage current is low. Under these circumstances, it is therefore not possible to increase the energy resolution in the measurement by providing better blocking contacts. Thus, a person skilled in the art is especially not interested in better blocking contacts.

11. Furthermore, there is really no motivation to replace Boron as a contact. As stated at the bottom of page 4 and the top of page 5 of our application, experiments have been performed by other groups to provide amorphous Germanium contacts. In these experiments, a structured metal layer sits on top of amorphous Germanium. The structure of the metal layer, however, was not carried through to the amorphous Germanium layer. The results of these experiments showed that a relatively poor energy resolution was achieved, and that a large number of measurement errors occurred.

12. A person of skill in the art would have known this at the time the application was filed, and therefore would have believed that replacing the Boron contact with an amorphous Germanium contact would yield a poor energy resolution. It was surprising to discover, on the other hand, that continuing the structure of the metallic layer through the amorphous Germanium layer into the crystalline bulk Germanium actually improved the energy resolution above that of unstructured amorphous Germanium layer(as described at point 11).

13. I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements are made with knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title XVIII of the United States Code and that willful false statements may jeopardize the validity of this Application for Patent or any patent issuing thereon.

Dated: 21. January 2008

Davor Protic

Davor Protic

Exhibit 1

to Declaration of Davor Protic

Germanium Detector Stocklist

PopTop Cryostats and Dewars

Non-PopTop Cryostats and Dewars

Cryostat and Dewar Drawings

Detector Element

GAMMA-X Germanium (HPGe) Coaxial Detectors (in PopTop Capsule or Streamline Cryostats)

For Compton-suppressed gamma spectroscopy, for measurements involving spectroscopy over the widest energy range, and in any situation where neutron da is likely.

- Efficiencies to over 100%
- PopTop flexibility
- Spectroscopy from 3 keV to 10 MeV
- ULTRA thin, ultra stable boron ion implanted outer contact
- High resistance to neutron damage
- Customer-repairable for neutron damage (option)
- Excellent timing characteristics
- Ideal for Compton-suppressed gamma spectroscopy
- Be window supplied with protective cover; Al or carbon fiber window option available additional charge
- High-rate indicator
- PLUS preamplifier option for ultra-high-rate applications
- Automatic high-voltage shutdown protects preamplifier input FET

The GAMMA-X detector is a coaxial Germanium (Ge) detector with an ultra-thin entrance wi While most coaxial detectors have entrance windows from 500- to 1000-µm thick, the entra window of the GAMMA-X detector is a 0.3-µm-thick, ion-implanted contact. Ion implantation results in a totally stable contact which will not deteriorate with repeated cycling.

Figure 8 compares ORTEC's GAMMA-X and GEM detector elements. The GAMMA-X detector element depicted is different from that of the GEM detector because the former's starting m is n-type germanium.

The GAMMA-X detector is the only Ge spectrometer designed for both gamma- and x-ray spectroscopy with high precision and efficiency for both. This point can be illustrated by com the GAMMA-X detector with a LEPS and with an HPGe coaxial detector (Fig. 9). The GAMMA- detector offers a combination of the performance of the LEPS at low energies and a coaxial detector at high energies.

High- and Low-Energy Performance of the GAMMA-X Detector

The high-energy performance of a GAMMA-X detector is defined by its relative efficiency, resolution, and peak-to-Compton ratio at ^{60}Co.

The low-energy performance of this detector is defined by its resolution at 5.9 keV, its activ surface area, and the detector window thickness.

The thickness of the entrance contact of the GAMMA-X detector is described by the ratio of t areas of two peaks of a readily available source. The peaks chosen are those of the 88-keV

gamma rays from the ^{109}Cd and of the 22.16-keV Ag K x rays from the same source. The warranted window attenuation ratio

$$W_E = \frac{\text{peak area at 22.16 keV}}{\text{peak area at 88 keV}}$$

is 20. Obviously, the ability to see and measure the resolution accurately at 5.9 keV speaks eloquently of the thinness of the entrance window.

Figures 10–12 show a comparison of the low-energy performance of a GEM HPGe coaxial de (Fig. 10), a 5-cm active area, 10-mm-deep LEPS (Fig. 11), and a GAMMA-X detector (Fig. 1:

In the GEM coaxial detector the thick (~700 µm) lithium-diffused outer contact completely a the Ag K x rays of the ^{109}Cd source (Fig. 10). Only the 88-keV gamma-ray line is visible. In GAMMA-X detector, the entrance window of the detector element itself is 0.3 µm thick. The rays are perfectly visible, with excellent peak-to-valley ratios (Fig. 12). The very low-energy escape peaks in Fig. 12 are totally missing in Fig. 10. Figure 11 shows the spectrum as obtai with an HPGe detector expressly designed for work at energies below 100 keV: a 5-cm activ area, 10-mm-deep LEPS. The spectra of Figs. 11 and 12 are quite similar.

Beryllium Window

Detectors supplied with 2-3/4-in.-diam endcaps (10 to ~35%) are supplied with 2-in.-diam windows; those supplied in 3-1/4-in.-diam endcaps (~30 to 65%) are supplied with 2-1/2-ir diam Be windows. These windows are 0.020 in. thick and have a transmission coefficient of at 5.9 keV. (Low-background carbon fiber windows are optional. See Figure 22 for transmiss characteristics of the Be and carbon fiber windows.) Detectors in 3-3/4-in.-diam. endcaps (~ 100%) receive 3.3-in.-diam. Be windows which are 0.030 in. thick.

Guaranteed Performance at 5.9 keV

To achieve good energy resolution at 5.9 keV, the technology of this state-of-the-art detectc must be well understood by the manufacturer. Resolution specifications stated only at 14 or keV can be misleading and may be indicative of having failed to master the technology.

High-Voltage Shutdown and High-Rate Indicator

GAMMA-X detectors have high-voltage shutdown and high-rate indicator protection features. LN_2 supply is exhausted and the detector begins to warm while high-voltage bias is applied (using the Model 659 Bias Supply), the high voltage automatically shuts off, thus protecting t FET from damage.

This is accomplished with a temperature sensor (located on the mount behind the detector) shuts down the high voltage before the molecular sieve can outgas and cause a dangerous h voltage arc. Using the high-leakage current of a warming detector to shut down the high vol can result in FET and detector damage.

Neutron Damage Resistance

In the GEM detector, in which the outer contact is positively biased, hole collection dominate charge collection process; in the GAMMA-X detector, electron collection is the dominant proc

Fast neutrons generate hole-trapping centers; that is, negatively charged defects that trap h
but not electrons.

Therefore, the GAMMA-X detector, in which the hole collection process is of secondary impor
is basically less sensitive to radiation damage than coaxial Ge devices in which the hole colle
process is of primary importance. These theoretical considerations have been experimentally
confirmed.[2]

Figure 13, a plot of the 1.33-MeV FWHM resolution as a function of fast neutron fluence for t
GAMMA-X and a GEM detector of the same efficiency, shows that the GAMMA-X detector is fa
more resistant to fast neutron radiation damage.[2] As noted, the detector temperature affect
radiation damage resistance to fast neutrons.

It should be noted that **once severe radiation damage has occurred**, the "longest mileag
obtained by avoiding cycling the detector to room temperature.[3] This is true for either p- or
Ge detectors. However, for slightly damaged GAMMA-X detectors (~0.1 keV degradation), cy
or even leaving the detector warm for an extended period, will have no unfavorable effect.[4]

GAMMA-X detectors should be maintained at a temperature as close to 77 K as possible to
minimize the extent of radiation damage. Therefore a streamline cryostat, with one less ther
connection, is a better choice than a PopTop for this purpose.

Customer-Neutron-Damage-Repairable Detectors

Repair of neutron-damaged GAMMA-X detectors can be performed at any of our worldwide r
facilities, or by you in your own laboratory. Contact us for information about our Customer-
Neutron-Damage-Repairable GAMMA-X detectors.

Options of Interest

- PLUS preamplifier option for ultra-high-rate applications.
- Carbon fiber window or all-aluminum endcap — on request, no additional charge.
- Non-PopTop low-background versions of the GAMMA-X detector are available.
- X-COOLER II option for practical LN2-free cooling.

Ordering Information

GAMMA-X Germanium (HPGe) Coaxial Detector* (Non-PopTop or PopTop)
For GMX Detector in PopTop capsule, add "P4" to the model no. [e.g., GMX10P4-70]
Endcap diameter must be specified, see Endcap Diameter Options [e.g., GMX10-70, GMX35P4-76]
FW.02M/FWHM Specification is Typical, NOT Warranted

Model No.	Relative Photopeak Efficiency (%)	Resolution		Peak-to-Compton Ratio	Peak Shape†		End Diam Opti
		@5.9 keV (eV FWHM)	@1.33 MeV (keV FWHM)		FW.1M/ FWHM	FW.02M/** FWHM	
GMX10	10	600	1.80	40:1	1.9	2.6	-7
GMX15	15	635	1.85	44:1	1.9	2.6	-7
GMX20	20	650	1.90	48:1	1.9	2.8	-7
GMX25	25	690	1.90	48:1	1.9	2.8	-70, -7

GMX30	30	715	1.90	52:1	1.9	2.8	-70, -7
GMX35	35	730	1.95	55:1	2.0	3.0	-70, -7
GMX40	40	760	1.95	59:1	2.0	3.0	-76,
GMX45	45	800	2.0	60:1	2.0	3.0	-76,
GMX50	50	800	2.2	58:1	2.0	3.0	-8
		(keV FWHM)					
GMX60	60	1.10	2.3	56:1	2.0	3.0	-83,
GMX70	70	1.10	2.3	60:1	2.0	3.0	-9
GMX80	80	1.10	2.3	63:1	2.0	3.0	-9
GMX90	90	1.20	2.4	64:1	2.1	3.1	-9
GMX100	100	1.20	2.5	64:1	2.2	3.2	-9
Options							
-A	For PopTop Capsule with 1.3 mm thick Al Window, add "-A" to the model no. [e.g., GMX90P4-95-A] (see Table 3 for transmission data)						
-C	Carbon Fiber Window (see Figure 22 for transmission data)						
-RB	Reduced Background PopTop Capsule with Carbon Fiber Endcap, add "-RB" to the model numbe GMX90P4-95-RB]						
-RB-B	Reduced background PopTop capsule with Be Window in Cu Endcap, add "-RB-B" to the model n [e.g., GMX10P4-95-RB-B]						
-PLUS	Ultra-high-count-rate Preamplifier, add "-PLUS" to the model number [e.g., GMX90P-95-PLUS for PopTop or GMX90-95-PLUS for Non-PopTop]						
SMART-1-N	SMART-1 detector option for negative bias detector. To order, add SMART-1-N as a separate lin						

*All GAMMA-X PopTop detector capsules include sealed detector element, preamplifier, high-voltage filter, and a Be window 0.02 inches thick and with diameter ≥ that of the detector element. Useful energy range is 3 keV to 10 MeV.

†FWHM = Full Width at Half Maximum; FW.1M = Full Width at One-Tenth Maximum; FW.02I Full Width at One-Fiftieth Maximum; total system resolution for a source at 1000 counts/s measured in accordance with ANSI/IEEE Std. 325-1996, using ORTEC standard electronics.

**Typical Value. Specification is in eV for efficiencies <60% and thereafter in keV.

NOTE: For those familiar with HPGe detector specifications, you will notice that ORTEC now (ONLY "first category" detector specifications. Recent process improvements now make this possible.

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Attachment 2

M. Amman, P.N. Luke, S.E. Boogs, NUCLEAR INSTRUMENTS AND METHODS IN PHYSICS RESEARCH A 579 (2007) 886-890

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Amorphous-semiconductor-contact germanium-based detectors for gamma-ray imaging and spectroscopy ☆

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Abstract

Germanium-based detectors are the standard technology used for gamma-ray spectroscopy when high efficiency and excellent energy resolution are desired. By dividing the electrical contacts on these detectors into segments, the locations of the gamma-ray interaction events within the detectors can be determined as well as the deposited energies. This enables simultaneous gamma-ray imaging and spectroscopy and leads to applications in the areas of astronomy, nuclear physics, environmental remediation, nuclear nonproliferation, and homeland security. Producing the fine-pitched electrode segmentation often required for imaging has been problematic in the past. To address this issue, we have developed an amorphous-semiconductor contact technology. Using this technology, fully passivated detectors with closely spaced contacts can be produced using a simple fabrication process. The current state of the amorphous-semiconductor contact technology and the challenges that remain are given in this paper.

PACS: 07.85.Nc; 29.40.Gx; 29.40.Wk; 95.55.Ka

Keywords: Gamma-ray imaging; Gamma-ray spectroscopy; Germanium detector; Orthogonal strip; Position sensing

1. Introduction

There are several advantages for choosing high-purity Ge for gamma-ray spectroscopy. These include (1) commercial availability of large detector volumes (10 cm diameter boules), (2) ability to fully deplete thick detector layers (> 1 cm), (3) relatively high atomic number, (4) near-perfect charge collection, and (5) favorable charge generation statistics. The first three advantages lead to high detection efficiency and the latter two to excellent energy resolution (<0.2% FWHM at 1.33 MeV). However, because of the small bandgap energy of Ge, the detectors do require cryogenic cooling (to near 100 K) in order to reduce the thermal generation of electron–hole pairs that tend to obscure the small signal current generated by the gamma-ray interactions.

Combining gamma-ray imaging with spectroscopy forms a powerful tool for basic scientific research and practical radioisotope detection and characterization. Gamma-ray imaging often relies on detectors that can accurately determine the location of the gamma-ray interaction events within the detector volumes as well as the deposited energies [1]. The development of high spectroscopic performance Ge-based imaging instruments has been hampered in the past by difficulties in producing such position-sensitive detectors. The subject of this paper is the detector technology developed at Lawrence Berkeley National Laboratory (LBNL) that enables the simple production of Ge-based gamma-ray detectors with fine spatial resolution. In particular, we describe the amorphous-semiconductor contact technology [2–9], its advantages, and the developmental work that remains to be done.

2. Amorphous-semiconductor contacts

A simple single-element Ge gamma-ray detector (see Fig. 1a) consists of a block of high-purity Ge material in

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which n+ and p+ impurity-doped electrical contacts have been fabricated on opposite sides of the block. The detector is operated as a fully depleted reverse-biased diode, and spectroscopy is performed by measuring the electron–hole pair charge generated by each gamma-ray interaction event within the detector. The standard contact technology for such a detector consists of a Li-diffused n+ contact and a B-implanted p+ contact. Both contact types are robust, can withstand high electric fields, and lead to low charge carrier injection.

To produce a position-sensitive detector for imaging applications, the electrical contacts on the detector are divided into segments as shown in Fig. 1b. This can be readily done on the B-implanted contact [10,11] but is problematic on the Li-diffused side because of the contact thickness and the continued Li diffusion into Ge at room temperature. Furthermore, the inter-contact surfaces for both contact types should be passivated to obtain long-term detector stability, thereby necessitating additional processing steps. An alternative technology capable of producing position-sensitive detectors is the amorphous-semiconductor contact developed at LBNL. With this technology (see Fig. 1c), the contacts are formed by first coating all surfaces of the Ge crystal with a thin film of high-resistivity amorphous semiconductor (typically Ge or Si). Metal layers in the desired pattern are then deposited on top of the amorphous layer to complete the contact fabrication. The physical contact area in such a detector is defined by this low-resistivity metallization. However, most of the important electrical properties of the contact structure are dictated by the amorphous-semiconductor layer and the amorphous-semiconductor to crystalline Ge interface. The advantages of this technology are (1) fabrication simplicity, (2) thin contact dead layers, (3) complete surface passivation, since amorphous Ge (a-Ge) layers are commonly used for Ge passivation, (4) fine achievable contact pitches, and (5) bipolar blocking contacts. Much of the remainder of this paper will focus on describing how the contacts function and the improvements needed to make this a more widely adopted contact technology.

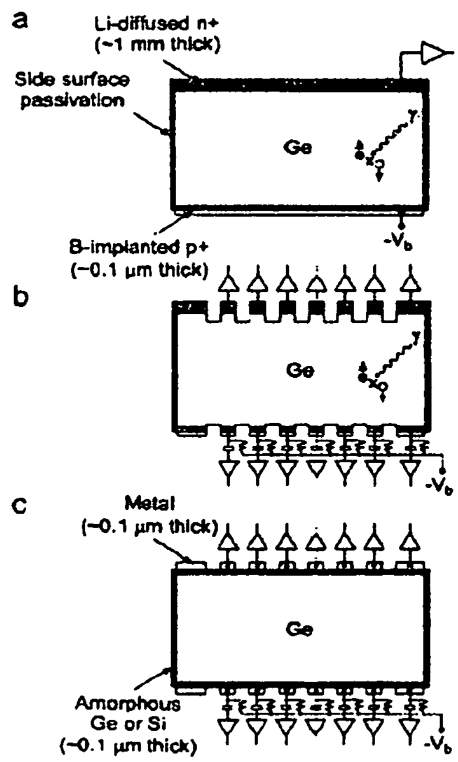

Fig. 1. Germanium-based gamma-ray detector configurations. (a) Conventional simple planar detector with Li-diffused anode and B-implanted cathode. (b) Position-sensitive detector produced using the conventional contact technologies. (c) Position-sensitive detector produced using the amorphous-semiconductor contact technology.

The amorphous-semiconductor contacts on Ge behave much like Schottky metal-semiconductor contacts with electron and hole barriers to charge injection typically equal to about half the bandgap energy of Ge. Consequently, the contacts can block the injection of both types of charge carriers, and the same contact can therefore operate with low leakage current under either bias polarity. This is in contrast to conventional impurity-doped contacts which block injection under only one bias polarity, and metal-Ge surface barrier contacts that typically block well only when negatively biased. The bipolar blocking behavior is demonstrated in Fig. 2 where the leakage current from an a-Ge contact detector is plotted for both negative and positive detector biases. Under either detector polarity, one of the a-Ge contacts is positively biased and

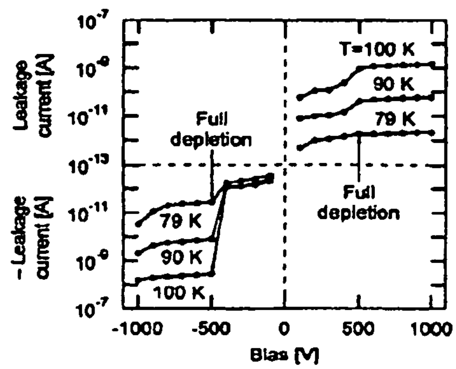

Fig. 2. Measured leakage current plotted as a function of bias voltage at three different temperatures for a p-type Ge detector fabricated with a-Ge electrical contacts (a-Ge/p-type Ge/a-Ge device). The detector thickness and active area were 1 cm and 1.7 cm², respectively.

the other negatively biased, yet low leakage is obtained at typical operating temperatures.

The electron or hole energy barrier to charge injection is an important property of a contact that dictates the level of charge injected into the detector which in turn can impact energy resolution if excessive. To determine the electron barrier of an amorphous contact, we fabricate a detector consisting of p-type Ge with a Li n+ contact on one side and the amorphous contact to be evaluated on the other. Under reverse bias, the depletion within this detector begins at the Li contact and, as the bias is increased, extends towards the amorphous contact. At full depletion, the field penetrates to the amorphous contact, and a step increase in the leakage current is observed that is a result of electron injection at the amorphous contact. By measuring this step height as a function of temperature and fitting the data to a simple thermionic emission model [12], we are able to extract out the electron barrier. An example measurement from an n+/p-type Ge/a-Ge detector is given in Fig. 3a, and the barrier height extraction is shown in Fig. 4 plot (a). Similarly, an n-type Ge detector with a B-implanted p+ contact (or Pd metal-semiconductor contact) on one side and the amorphous contact on the opposite side can be used to determine the hole barrier of the amorphous contact. An example measurement from a Pd/n-type Ge/a-Ge detector is shown in Fig. 3b and the hole barrier height determination in Fig. 4 plot (b). From simple Schottky contact theory, the sum of the electron barrier and the hole barrier for a particular contact should equal the Ge bandgap energy. From Fig. 4, we see that the sum for this particular a-Ge contact is 0.68 eV and is reasonably close to the Ge bandgap energy (at the average measurement temperature of 135 K) of 0.72 eV.

The barrier heights of the amorphous-semiconductor contacts depend in part on the semiconductor used and the method by which they are deposited. This is an important tool that can be used to optimize detector performance. Our standard method to deposit the amorphous films is rf sputtering in pure Ar and Ar–H_2 gas mixtures. The addition of H_2 to the sputter gas produces a-Ge and a-Si films of substantially higher resistivities than those obtained with pure Ar sputtering and also impacts the barrier heights. A summary of the barrier heights measured for a few different types of amorphous-semiconductor contacts is given in Table 1 [13]. The data show that a-Ge sputtered in pure Ar (a-Ge (Ar)) produces electron and hole barriers of nearly the same value, which is approximately half of the Ge bandgap. If, for fabrication simplicity, a single contact process were used to produce all contacts on a detector, it would seem that the a-Ge (Ar) contact would be the best since it should lead to the lowest detector leakage. However, the resistivity of the a-Ge (Ar) can potentially be low enough to degrade energy resolution as a result of the Johnson noise associated with the low inter-contact resistance caused by the a-Ge (Ar) layer. The addition of H_2 to the sputter gas increases the a-Ge film resistivity by several orders of magnitude and solves this

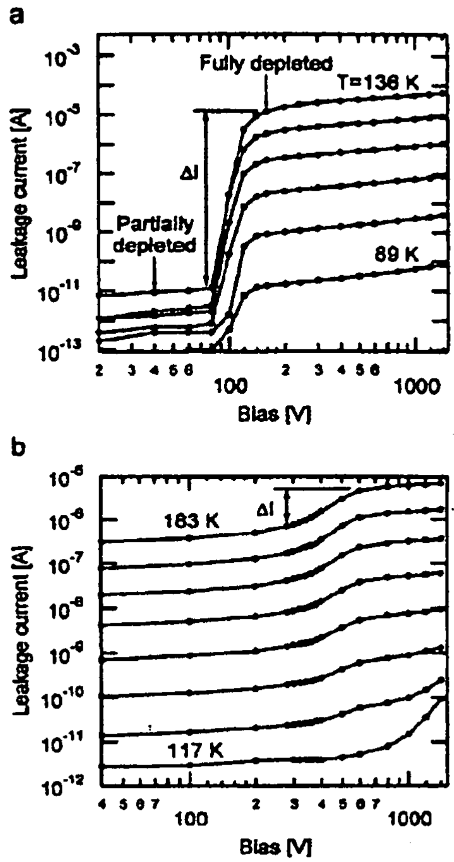

Fig. 3. Measured leakage current as a function of bias voltage for Ge detectors at various temperatures. (a) Detector with a configuration of Li diffusion/p-type Ge/a-Ge (Ar + 17.5% H_2). The detector thickness and area were 0.6 cm and 3.5 cm^2, respectively. (b) Detector with a configuration of Pd/n-type Ge/a-Ge (Ar + 17.5% H_2). The detector thickness and area were 0.6 cm and 3.1 cm^2, respectively.

problem. In part, for this reason, we typically use a-Ge (Ar + H_2) to produce finely segmented detectors.

Detectors produced with a-Ge (Ar + 17.5% H_2) contacts for both the positive and negative contacts operate with low leakage and good spectroscopic performance at temperatures near that of liquid nitrogen. If, however, the detector temperature is increased to about 90 K or above, the leakage current can be significant enough to degrade the detector energy resolution. The temperature dependence of the leakage current for an all a-Ge (Ar + 17.5% H_2) contact detector is shown in Fig. 5a. The leakage current step increase exhibited in the plots results from electron injection at the negative contact when full depletion is reached. As the data of Table 1 indicate, the addition of H_2 to the sputter gas has not only increased the a-Ge film resistivity, but it has also increased the hole

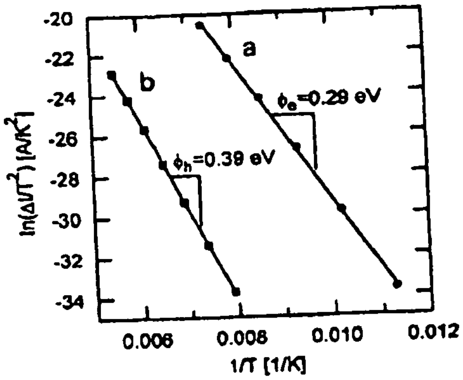

Fig. 4. Plot illustrating the barrier height extraction from the data of Fig. 3.

Table 1
Extracted barrier heights for amorphous semiconductor contacts on high purity Ge

Contact	ϕ_e (eV)	ϕ_h (eV)	$\phi_e+\phi_h$ (eV)	ρ (Ωcm)
a-Ge (Ar)	0.36	0.34	0.70	$\sim10^6$–10^8
a-Ge (Ar + 17.5% H_2)	0.29	0.39	0.68	$\sim10^{11}$
a-Si (Ar)	0.39	0.28	0.67	$\sim10^9$

The sum of the electron and hole barrier heights and film resistivities measured at 77 K are also listed.

barrier at the expense of the electron barrier. The reduced electron barrier is then the primary cause of the leakage in Fig. 5a. We have demonstrated that replacing the negative contact with the higher electron barrier a-Si contact substantially lowers the detector leakage at the higher temperatures. This is shown in Fig. 5b. Such a detector configuration is appropriate when higher operating temperatures are desired.

Germanium-based gamma-ray detectors with a-Ge contacts have successfully been produced for several prototype imaging instruments [4,14–17]. A typical configuration for these detectors is the orthogonal-strip geometry with strip pitches between 1 and 2 mm and detector volumes as large as 160 cm^3. Excellent energy resolution and three-dimensional position detection [6,7,18] are achieved with these detectors. We have also demonstrated the fine-electrode segmentation capability of the contacts by fabricating strip detectors with pitches down to 50 μm.

3. Future improvements

Despite the substantial success achieved with Ge-based detectors fabricated using amorphous-semiconductor contacts, issues remain to be resolved before the full potential of the devices will be realized in large-scale instruments. These issues include excessive leakage at temperatures significantly above that of liquid nitrogen, leakage current degradation with temperature cycling, and charge collection to inter-contact surfaces. The excessive leakage current issue was discussed in the previous section and, as we have shown, can be addressed through the development and optimization of the a-Ge/Ge/a-Si detector configuration and other similar structures.

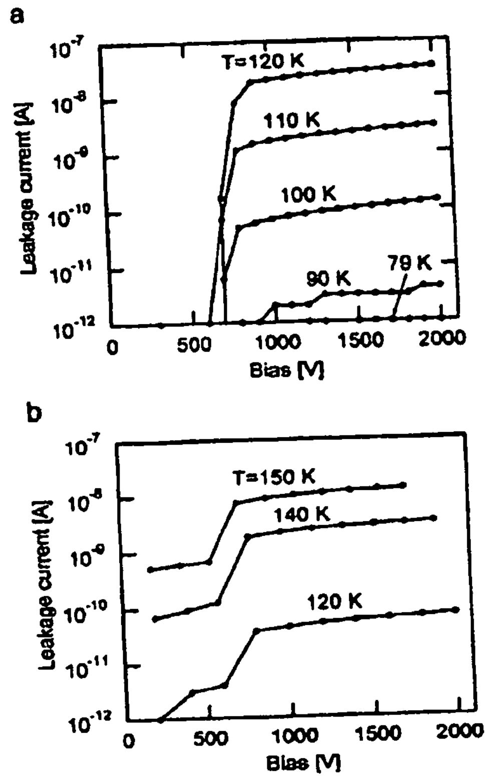

Fig. 5. Measured leakage current as a function of bias voltage for Ge detectors at various temperatures. (a) Detector with a configuration of a-Ge (Ar + 17.5% H_2)/p-type Ge/a-Ge (Ar + 17.5% H_2). The detector thickness and active area were 1 cm and 1 cm^2, respectively. (b) Detector with a configuration of a-Ge (Ar + 17.5% H_2)/p-type Ge/a-Si (Ar + 7% H_2). The detector thickness and area were 1 cm and 1 cm^2, respectively.

Cycling the temperature of an amorphous-contact Ge detector from cryogenic temperatures to room temperature and then back to a low temperature again typically causes the leakage current of the detector to increase at the operating temperature. Such temperature cycling is unavoidable in the detector evaluation and instrument assembly process. The gradual increase in the leakage caused by this cycling can ultimately lead to degraded energy resolution. We have found that the extent of this degradation is dependent on the parameters used during the sputter deposition of the amorphous-semiconductor layer (temperature, power, sputter gas mixture and pressure) and can be substantially reduced through

judicious selection of the parameters. However, additional work in this area is necessary to optimize the sputter deposition process for improved cycling behavior, verify the reproducibility of the results, and determine the robustness of the improved process when applied to large-area segmented detectors.

When charge from a gamma-ray interaction event is collected to the surfaces separating adjacent contacts rather than to the contacts themselves, a deficit in the measured charge results that can degrade spectroscopic performance [5–7]. The extent of this incomplete charge collection is affected by the nature of the amorphous-semiconductor layer on the inter-contact surfaces. Several possible approaches exist to lessen or eliminate this problem and include (1) optimizing the amorphous layer and surface processing so that charge accumulation inhibits the collection of signal charges at the inter-contact surface [7], (2) minimizing the area of inter-contact surfaces at the price of greater inter-contact capacitance and, consequently, electronic noise, (3) etching away the amorphous-semiconductor surface layer between contacts [8], (4) making use of field-shaping electrodes [6,7], and (5) signal processing to correct for the charge loss. Further work in this area is required to determine the effectiveness and reliability of each approach as well as to identify any shortcomings so that the best solutions can be applied to future detectors.

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RELATED PROCEEDINGS APPENDIX

None.